9.6 REACTOR ENGINEERED SAFETY FEATURE AIR CLEANING SYSTEMS

9.6.1 ESF SYSTEMS USED IN NUCLEAR POWER PLANT REACTORS

Three broad categories of ESF air cleaning systems are in use at nuclear power plant reactors. These categories include (1) systems designed to capture gaseous and particulate releases within the enclosed volume to which they have accidentally escaped (i.e., containment post-accident air cleaning system); (2) systems intended to collect and process the leakage from an enclosed volume into which an accidental release has occurred; and (3) systems that are capable of cleaning ambient air which may have been contaminated by an accidental release to the environment so that it is safely breathable (i.e., the control room protection air cleaning system). The first of these systems is located within the reactor containment building or within the fuel handling or storage facility, and takes both suction and discharges into the enclosed volume in which it operates. The second of these systems draws air from enclosed volumes surrounding the potential accident location where the leakage is to be attenuated. This system may be located either within or outside the volume from which it takes suction while it discharges its cleaned air flow into the environment. The third system draws outside air from the environment, and its output is used to pressurize the enclosed volumes to be inhabited during potential accidents, thereby minimizing diffusive entry into these protected volumes.

9.6.2 REACTOR CONTAINMENT

Requirements of the containment post-accident air cleaning system largely depend on the type of containment employed.[50] There are five basic types of reactor containment: single-pressure containment, double-pressure containment, pressure containment with shield building, vented confinement, and containment/confinement.

In pressure containment (**FIGURE 9.23**), the reactor vessel head space (or head space vault) and reactor bay are enclosed by a large (2 by 106 ft^3 or larger volume), ASME Code-constructed,[51]

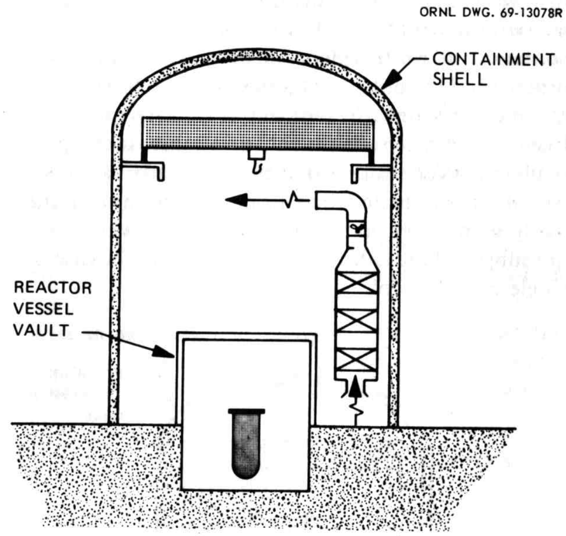

Figure 9.23 – Pressure containment with internal recirculating or kidney ESF postaccident air cleaning system

leaktight (maximum permissible leak of 0.1 percent of volume/24-hr period), steel or steel and concrete vessel. The vessel is designed to withstand the maximum temperatures and pressures developed in the DBA and SSE. A recirculating air cleaning system is provided to minimize the airborne radioactive material that escapes from the pressure containment. Pressure containment with internal recirculating (or kidney) air cleaning facilities was used for several early pressurized water reactors (PWRs). Internal recirculating systems have several disadvantages. First, they may be exposed to an extremely severe post-accident service environment (temperatures exceeding 300 degrees Fahrenheit (149 degrees Celsius) pressures as high as 65 psia over the 1- to 10-sec period following a core disruptive accident; relative humidity of 100 percent; air densities of two to three times normal; and, if containment sprays are used to reduce pressure, sensible moisture in a heavy rain condition in a PWR. Second, the filters and adsorbers may have low reliability under this environment. Third, it may be impossible to repair or replace air cleaning system components following an accident. The internal recirculating or kidney system concept has been abandoned for light water reactors (LWRs).

An alternative to the internal kidney system is the external recirculating system shown in **FIGURE 9.24**. In this design, air cleaning

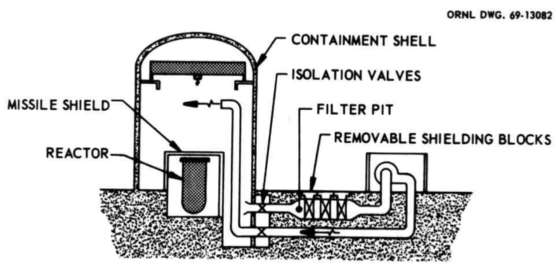

Figure 9.24 – Pressure containment with external recirculating postaccident air cleaning system

components are located outside of the containment structure. Isolation dampers in the ducts leading to and from the containment structure permit isolation of the air cleaning system components until the initial pressure transient has passed and pressure across the system can be equalized. System components are protected from missiles in the containment, and, with redundant systems, can be repaired or replaced remotely if necessary (see Section 9.2). Bypass dampers can be provided to permit operation of the system in the once-through mode for purging the containment. This concept, which was first proposed in the earlier edition of this handbook,[52] has been considered for power reactors.

In the double containment concept, a pressure containment similar to that discussed above surrounds an inner ASME Code-constructed pressure containment that surrounds only the reactor vessel head space. The inner vessel, which must be removable to permit access to the reactor core, has a permissible leak rate of 1 volume/24 hrs, but is designed to withstand the maximum pressures and temperatures of a DBA. Kidney-type ESF containment post-accident air cleaning facilities are provided in the outer containment space. Since these facilities "see" only the radioactive material that leaks from the inner containment, and most of the particulate matter emitted in a core disruptive accident would settle or plate out in the inner containment, the loading and environmental conditions to which they are subjected are substantially less than in the case of single containment.

Pressure containment with shield building (**FIGURE 9.25**) has been employed in many PWRs (e.g., Catawba and McGuire) and in some boiling water reactors (BWRs). In this concept, an annular shield building surrounds the pressure containment structure. Any leakage from the primary containment is to the shield space. ESF air cleaning facilities are provided in or adjacent to the shield space. These may be once-through, discharging to the atmosphere, once-through and discharging back to the primary containment (pump-back), or recirculating within the shield space. In most cases, shield space is maintained at a lower pressure than either the primary containment or the atmosphere. Shield building ESF air cleaning facilities are small (4,000- to 6,000-cfm installed capacity in the basic system with 100 percent redundancy) compared with in-containment kidney systems (as large as 100,000-cfm installed capacity in the basic system, usually with 100 percent redundancy). As the components are protected from the severe post-accident environment of the primary containment, shield building systems are obviously much more reliable. A variation on the shield building concept is the penetration vault that has been used in some reactors. In this design (**FIGURE 9.26**), the shield volume surrounds only the area of the containment structure at which steam lines, piping, electrical conduits, and other penetrations occur.

Vented confinement (**FIGURE 9.27**) was used in the DOE production reactors that were shut down following the Chornobyl accident; it is still used in most research reactors. In this design, the reactor vessel head space (or head space vault) and reactor bay are enclosed in a low-leakage building of special, but essentially conventional, design.[55]

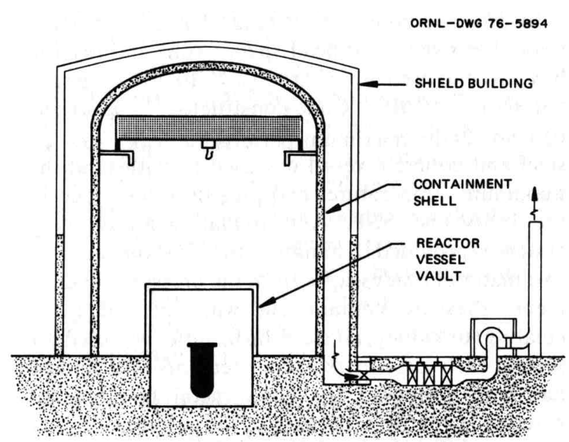

Figure 9.25 – Pressure containment with shield building

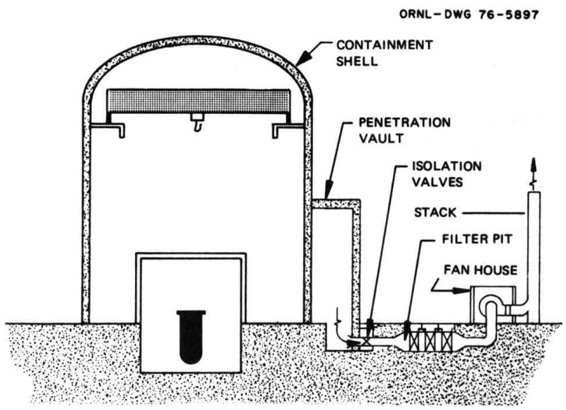

Figure 9.26 – Pressure containment with vented penetration vault

The containment structure is not an ASME Code vessel. ESF air cleaning facilities may be either recirculating, as in the Savannah River reactors, or once-through, discharging to the atmosphere through a high stack (elevated release may reduce offsite doses by an order of magnitude or more compared with ground-level release). The confinement building is maintained at negative pressure relative to the ambient pressure by the exhaust system. In most DOE and research reactors, the same set of air cleaning facilities serves both the normal operational and post-accident functions.

Containment/confinement (**FIGURE 9.28**) is employed in most BWRs. The reactor vessel or reactor vessel head space is enclosed in an ASME Code-constructed containment vessel which, in turn, is surrounded by a confinement building similar to that used for vented confinement.

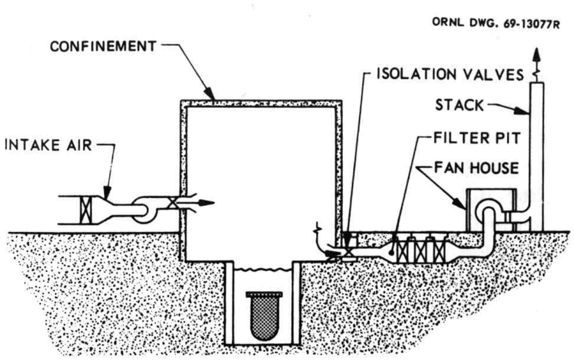

Figure 9.27 – Vented confinement as used in production and research reactors

Unlike vented confinement, however, the air cleaning system components are not exposed to the severe post-accident environment of a DBA and are required to remove only the small quantity of material that leaks from the containment vessel or around containment penetrations. Therefore, ESF air cleaning facilities are small, ranging from as low as 4,000-cfm basic system airflow to as much as 16,000 cfm for BWR standby gas treatment systems, depending on the size of the confinement building. In all cases, 100 percent, redundancy of ESF air cleaning facilities is required.

If air cleaning equipment is located high in the containment or confinement building, as was done in some reactors to conserve space on the reactor or fuel-loading floor, protection against extreme shaking in the event of an earthquake is needed.

In all containment concepts, non-ESF air cleaning facilities are usually provided air cleaning in the containment or confinement building under normal operating, maintenance, or shutdown conditions, as well as containment purge. Non-ESF systems are generally much smaller than in-containment post-accident air cleaning systems and are not required to be redundant. In commercial power reactors, non-ESF systems are independent of the ESF systems and may or may not be shut down in the event of an accident depending on the design basis of the systems. Many times, the availability of a non-ESF system during is advantageous if power is available and the system is operational. Although non-ESF systems do not have to meet the post-accident and

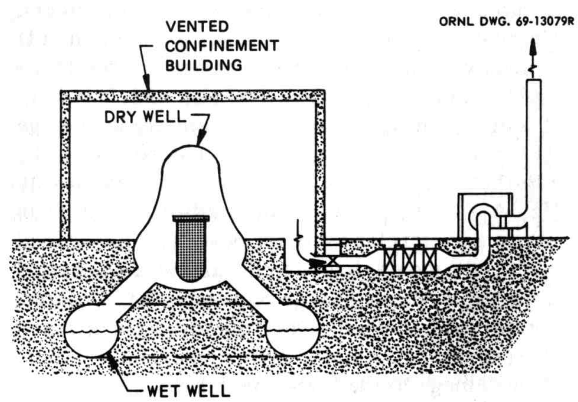

Figure 9.28 – Containment/confinement for BWR with once-through, external-standby gas treatment system

earthquake survival requirements of the ESF system, if they are located in areas where ESF facilities of any type exist, they must be designed at least to resist falling or tearing loose during a core disruptive accident or SSE.

9.6.3 Light Water Reactors

Guidelines for the design of LWR ESF air cleaning facilities are given in USNRC Regulatory Guide 1.52,[58] which recommends a sequence of air cleaning components consisting of demister, prefilter, HEPA filter, adsorber, and final HEPA filter stages. A heater is also recommended upstream of the adsorbers to maintain the relative humidity of the air entering the adsorbers at less than 70 percent following a LOCA. Because radioiodine is the contaminant of major concern in the event of an LWR LOCA, the need for two stages of HEPA filters is often questioned, particularly because prefilters are also required upstream of the first-stage HEPA filters. The first-stage HEPA filters have two functions: (1) protection of the adsorbers from particulates which could "blind" the adsorbent granules and (2) holdup of iodine-bearing particles. Without the first-stage HEPA filters, these particles could penetrate the adsorber beds and be caught on the downstream HEPA filters, and the iodine adsorbed on them [which accounts for 5 percent of the postulated iodine load (see Chapter 3, Section 3.4) would desorb to the air being discharged from the system. The second-stage HEPA filters prevent the loss of iodine-bearing adsorbent fines and also provide backup protection in the event of failure of or damage to the first-stage HEPA filters. [ASME AG-1[18] now allows for substitution of the "downstream" HEPA bank with a high-efficiency (90-95 percent) ASHRAE-class filter bank.]

Components of the ESF air cleaning system must be designed, constructed, tested, and maintained to ensure effective, reliable operation when subjected to the postulated environment and service conditions of the DBA. The least stringent post-accident environment and service conditions would be encountered in the confinement building of a containment/confinement system or in the shield building of a pressure-containment/shield building system. Although the ESF air cleaning facilities would have to be able to withstand the SSE and a humidity of 100 percent, pressure and temperature transients would be nil, and particulate concentrations and radioactivity levels would be relatively low compared with vented-containment or pressure-containment systems. Other conditions that have to be considered are pressure transients due to a design basis tornado or to an inadvertently opened or closed damper, as well as shock, vibration, and physical displacement resulting from a postulated simultaneous SSE.

A simple vented confinement without an inner containment would be subject to much more stringent post-accident service conditions than the containment/confinement or pressure-containment/shield building designs. Post-accident service conditions may include radiation levels in air cleaning components of 10^7 to 10^8 rads, temperatures as high as 275 degrees Fahrenheit (135 degrees Celsius), and pressures of 2 to 3 psi above atmospheric pressure, as well as large volumes of condensing steam and possible sensible moisture. In addition, the system must be designed to withstand the DBE and DBT. The most severe post-accident conditions would be encountered in a pressure containment with an ESF kidney air cleaning facility. In addition to high radiation levels (10^7 to 10^8 rads), high temperatures (up to 275 degrees Fahrenheit (135 degrees Celsius), and large volumes of condensing steam and sensible moisture, ducts and equipment housings may be subjected to high collapsing pressures. These pressures can be as great as 40 to 45 psig during the first few minutes following the core disruption due to the lag of pressure rise in the duct relative to pressure rise in the containment unless pressure-relief dampers are provided. Fans and motors are required to operate at very high temperatures in saturated air and in air densities of 2 to 3 atmospheres. If chemical sprays are discharged in the containment (to reduce pressure and react with airborne iodine), corrosion of metal parts and chemical attack of filter and adsorber media may also take place.

In all reactor post-accident situations, fission-product-decay heating of carbon in the adsorbers must be considered. With insufficient provision for cooling in the event of main fan failure, heating of the carbon may result in desorption of the already trapped radioiodine (which would constitute failure of the system) or of the impregnants on which radioiodine trapping depends, or even in ignition of the carbon. Tests have shown that deluge water sprays, which are often provided for extinguishing carbon fires, are of limited value.[59] In addition, the water washes out both the impregnant and any trapped radioiodine, thus causing further loss of iodine containment and creating a substantial liquid waste problem.

Demisters are required in all systems because of high sensible moisture and possible steam loadings, which can plug HEPA filters and degrade the effectiveness of activated carbons for organic iodine compounds. Demisters require adequate drains to carry the collected water to the liquid waste system. If drains are not properly designed and maintained, a bypass of the HEPA filters and adsorbers may be created (through the drain system), which would result in failure or degradation of the air cleaning function. Controls, instruments, sensing and air lines, electrical equipment, and electrical wiring that serve the air cleaning system must also be designed to withstand the postulated post-accident environment and conditions without failure. Redundant-unit ductwork and equipment must be geographically isolated, shielded, or installed in individual vaults to protect against single failure from missiles resulting from burst piping or failed equipment and from falling pipes, equipment, and ducts. Redundant units are always required to provide backup air cleaning capacity in the event of on-line unit failure. Provision for remote maintenance, though rarely considered, is desirable to permit the reactivation of failed units or the replacement of damaged or failed components.

9.6.4 Control Room Protection Air Cleaning Systems

Control room habitability air cleaning systems are ESF systems that must meet the requirements of USNRC Regulatory Guide 1.52.[58] Unless the internal components (filters, adsorbers) are located at the wall penetration of or within the controlled space, the system is generally of forced-flow configuration and operates in a recirculating mode. In most cases, the air cleaning facilities are external to the control room (controlled space). Positive pressure in the housings and ducts downstream of the fan minimizes in-leakage of potentially contaminated air from building spaces surrounding the control room. Most systems have provisions for obtaining makeup air from outside of the building, with isolation dampers to cut off makeup airflow if necessary. The location of control room protection system components within the control room has the advantage of maintainability under accident conditions; however, its disadvantage is that maintenance operations must be conducted within the control room, an activity that may be untenable to some operators.

The component train of a control room habitability system should include a prefilter, HEPA filter, adsorber, and second-stage HEPA filter or 90 to 95 percent postfilter. Prefilters are recommended even though the system recirculates very clean air, because the lint generated by personnel moving about in occupied spaces can bridge the pleats of HEPA filters, reducing their capacity. Makeup ducts should be fitted with prefilters and one stage of HEPA filters, and should have a high-quality isolation damper to cut off the makeup air in the event of a release of toxic or debilitating industrial gases (e.g., chlorine) in the area of the makeup intake. Redundancy is necessary and is usually provided by two or more totally independent and geographically isolated systems, each capable of furnishing the needs of the control room.

9.7 Fuel Reprocessing Plant Air Cleaning

9.7.1 Overview

Air cleaning requirements in fuel reprocessing facilities differ greatly from those for power reactors. Basically, the difference stems from the fact that day-to-day operations in a reactor are clean, but day-to-day operations in a reprocessing facility are inherently dirty. In a reactor, air cleaning facilities are designed to accommodate a large radioactivity release under accident condition, whereas the fuel reprocessing facility must accommodate the potential for smaller, but still substantial, releases under normal operating conditions. Effluent air and gases from reprocessing operations are likely to contain